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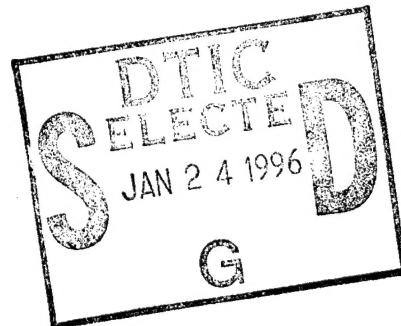
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The Aeronautical Research
Institute of Sweden

FFA TN 1982-26



FATIGUE EVALUATION OF WTS-3 GLASSFIBRE BLADE MATERIAL

BY

ANDERS F. BLOM

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Institute of Sweden
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FATIGUE EVALUATION OF WTS-3 GLASSFIBRE BLADE MATERIAL

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Anders F. Blom

Abstract

A first step in assessing the fatigue properties of the WTS-3 wind turbine blade material has been undertaken. Hereby flat test specimens of filament-wound material have been used for the fatigue tests. Wöhler-diagrams (SN-curves) have been produced both at purely tensile loading ($R = \sigma_{\min} / \sigma_{\max} = 0$) and at completely reversed loading ($R = -1$). The results show, as expected, that compressive loads are detrimental, due to local fibre-buckling, resulting in a substantial lowering of the entire SN-curve.

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1 INTRODUCTION

A first step in assessing the fatigue properties of the WTS-3 wind turbine blade material has been undertaken. Hereby flat test specimens of filament-wound material have been used for the fatigue tests. Wöhler-diagrams (SN-curves) have been produced both at purely tensile loading $R = \sigma_{\min}/\sigma_{\max} = 0$ and at completely reversed loading $R = -1$. The results show, as expected, that compressive loads are detrimental, due to local fibre buckling, resulting in a substantial lowering of the entire SN-curve.

2 SPECIMENS AND MATERIAL

The WTS-3 wind turbine blade is a shell structure, see Fig. 1 [6], made of a filament wound glass reinforced epoxy material. The load carrying member of the construction is the spar which forms the leading edge cell. The trail edge cell provides for the aerodynamic contour of the airfoil. The blade root is bonded and bolted to an inner and an outer retention ring for attachment to the hub.

The material in both the spar and in the shell is a laminate consisting of E-glass filaments bonded with an Epon 826/Jeffamine D-230 epoxy resin.

Fibre orientation in the spar is changing gradually from $\pm 30^\circ$, to the span direction, in the inboard region to $\pm 20^\circ$ in the tip region. In the shell 23% of the filaments are oriented at 90° to the span direction, these filaments form the top and bottom layers, and the remaining 77% of the filaments are oriented at $\pm 60^\circ$ to the span direction.

For this study it was agreed [1-4] to use specimens as shown in Fig. 2 with a fibre orientation of $\pm 30^\circ$ to the load axis. These specimens were fabricated from a filament wound cylinder, made by Hamilton Standard.

The free length of the specimens is short enough to avoid Euler-buckling why the same kind of specimen is used both under tensile and compressive loading.

3 EXPERIMENTS AND RESULTS

All test specimens were provided with tabs, see Fig. 2, in order to protect the fibres from the hydraulic grips. The fatigue tests were carried out in closed-loop servo-hydraulic test machines at a controlled frequency of 10 Hz in order to avoid any temperature rise due to hysteretic heating. All tests were performed in a laboratory environment with normal humidity and a temperature $T \approx 22^\circ\text{C}$.

The first set of experiments were carried out at a stress ratio $R = \sigma_{\min}/\sigma_{\max} = 0$, i.e. under a purely tensile loading. The results from these tests are summarized in Fig. 3 and Table 1.

The second set of data were produced at a stress ratio $R = -1$, i.e. under completely reversed loading. These data are summarized in Fig. 4 and Table 2.

It is found, as expected, that compressive loading results in shorter fatigue life than tensile loading does. This is due to local fibre buckling when the laminate is loaded in compression.

4 COMPARISON OF RESULTS WITH HS-DATA

In Fig. 5 are shown tensile fatigue test data, obtained from Hamilton Standard [5], for a $\pm 30^\circ$ filament wound laminate of the same material that is being studied in the present work. The data in Fig. 5 were produced with a stress ratio $R = 0.1$.

In order to compare the data in Fig. 3 with those in Fig. 5 we assume that the ultimate tensile strength (UTS) of the laminates would be the same irrespective of the tests being performed by Hamilton Standard or the FFA.

For flat specimens, as shown in Fig. 2, the ultimate tensile strength is given to 40 000 psi [5] which corresponds to 275.7 MPa.

Measurements performed at FFA on the same kind of specimens that are being fatigue tested give $UTS = \frac{960.6}{t}$ [MPa] where the thickness t of the tested specimens varies between 3.8-3.9 mm.

As this value of UTS is lower than that one obtained by Hamilton Standard it is likely that there is more resin in the FFA-specimens than in the HS-specimens. Measurements show that the FFA-specimens have a resin content of about 31 weight per cent. Since most of the load is carried by the fibres we will use an effective thickness $t_{eff} = 960.6/275.7 \approx 3.5$ mm when comparing the two different sets of fatigue data in Figs. 3 and 5 respectively.

The compared data are shown in Fig. 6 and it is seen that longer lifetimes were obtained at the FFA than at Hamilton Standard. This may partly be explained by mean stress effects, the experiments being performed with $R = 0$ at the FFA and $R = 0.1$ at HS. Other possible reasons for the difference could be different tabs on the specimens, different clamping devices or different test frequencies.

5 DISCUSSION AND FUTURE WORK

The fatigue mechanism for an angle-ply laminate with $\theta < 45^\circ$ (θ = angle between fibres and load direction) is delamination which will initiate at the free edges of a laminate due to the existence of interlaminar shear stresses at these edges [8].

The tested specimens are therefore likely to have yielded conservative results since the wind turbine blades do not have any free edges.

Fatigue damage in angle-ply laminates with $\theta > 2^\circ$ is matrix controlled [8]. Thus we may expect the fatigue properties of the laminate to deteriorate when tests are performed in a humid environment and/or at elevated temperatures.

It is therefore suggested to perform a new series of tests in a similar manner as described earlier in this report but in moisture and at the maximal design temperature $T = 95^\circ\text{F} \approx 35^\circ\text{C}$.

6 REFERENCES

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- [3] Beggs, J.C. Letter 3.1.1.48 Hamilton Standard - FFA, 16/11 1979
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- [6] United Technologies Hamilton Standard: WTS-3 Blade Material, Strength Characterization Program, Report HSER 8197, 1981
- [7] United Technologies Hamilton Standard: Aerodynamic and Structural Design Report Model WTS-3 Wind Turbine Rotor System, Report HSER 8146, 1981
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No	Width [mm]	Load [kN]	σ_F [MPa]	N (Cycles)	% UTS	Comment
						Min Max
1	50.8	0	49.0	275.6	1	100
2	50.7	0	48.5	273.3	1	100
3	50.5	0	36.0	203.7	< 10	73.9
4	50.7	0	10.0	56.4	2×10^7	20.4 Not failed
5	50.8	0	29.9	163.1	430	59.2
6	50.8	0	25.0	140.6	4600	51.0
7	50.0	0	20.0	114.3	89800	41.5
8	50.6	0	25.0	141.2	4200	51.2
9	50.0	0	17.0	97.1	768700	35.2
10	50.6	0	20.0	112.9	35100	41.0
11	50.6	0	20.0	112.9	31300	41.0
12	50.6	0	16.0	90.3	1841500	32.8
13	50.7	0	25.0	140.9	2640	51.1
14	50.7	0	20.0	112.7	6200	40.9
15	50.6	0	20.0	112.9	46300	41.0
16	50.7	0	16.0	90.2	227009	32.7 overload
17	50.8	0	14.0	78.7	1363000	28.5
18	50.4	0	12.0	68.0	11254000	24.7
19	50.6	0	16.0	90.3	2685200	32.8
20	50.7	0	15.0	84.5	779200	30.6
21	50.6	0	15.0	84.7	602100	30.7
22	50.7	0	15.0	84.7	567900	30.7
23	50.8	0	14.0	78.7	4386000	28.5
24	50.7	0	18.0	101.4	125770	36.8

Table 1 Results R = 0. Effective thickness $t_{eff} = 3.5$ mm
 $\sigma_{UTS} = 275.7$ MPa

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No	Width [mm]	Load		N [cycles]	Comment
		Min	Max		
25	50.8	-20.0	20.0	400	
26	50.8	-15.0	15.0	1000	
27	50.5	-10.0	10.0	32000	
28	50.9	- 9.0	9.0	359300	
29	50.7	- 9.0	9.0	92000	
30	50.7	-10.0	10.0	29900	
31	50.8	- 9.0	9.0	327900	
32	50.8	- 8.0	8.0	660400	
33	51.0	- 7.0	7.0	4175800	
34	50.8	- 7.0	7.0	4153400	
35	50.7	- 6.0	6.0	10400000	Not failed
36	50.9	-12.0	12.0	4900	
37	50.9	-15.0	15.0	1300	
38	50.9	-10.0	10.0	80300	
39	51.0	- 7.0	7.0	3975500	
40	50.8	-15.0	15.0	700	

Table 2 Results $R = -1$. $t_{eff} = 3.5$ mm

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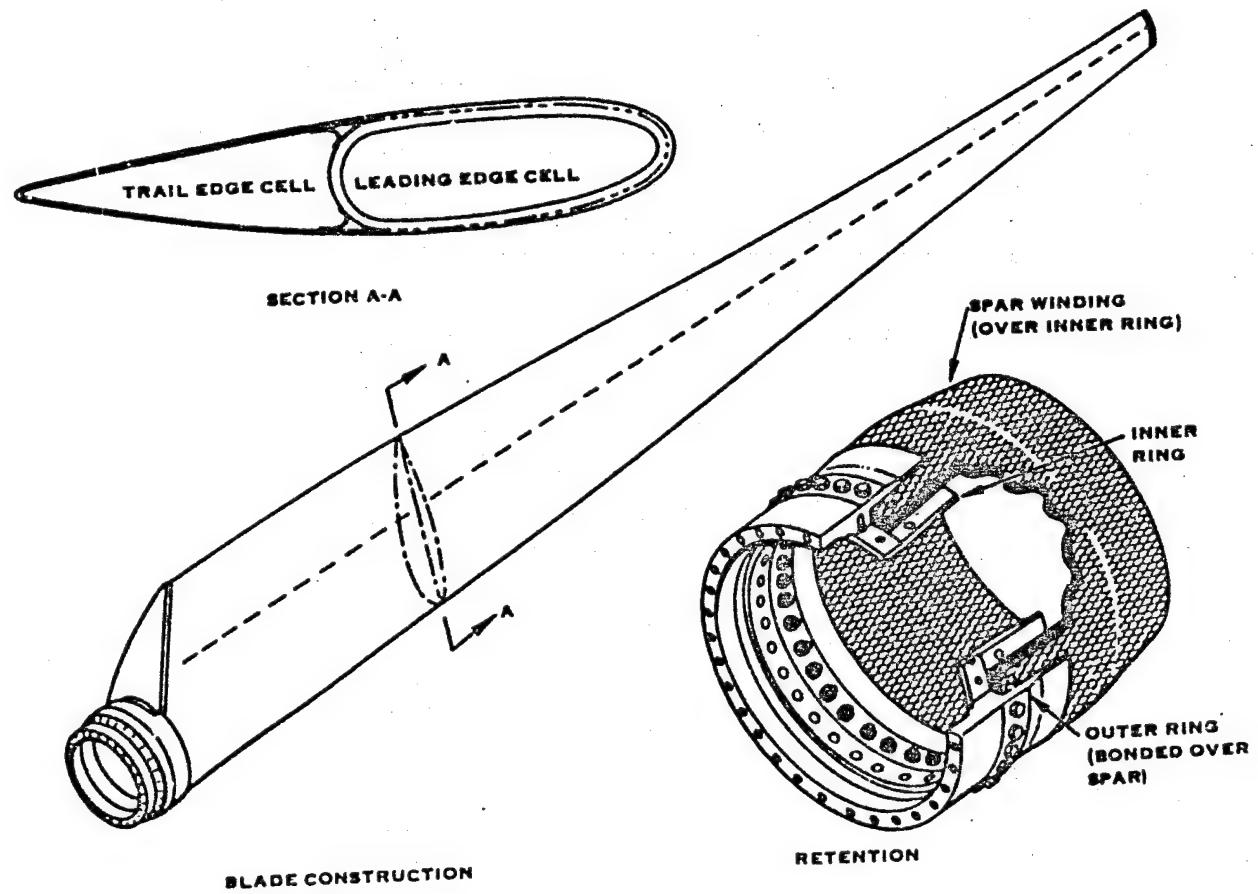


Fig. 1 WTS-3 blade construction
from Ref. [6]

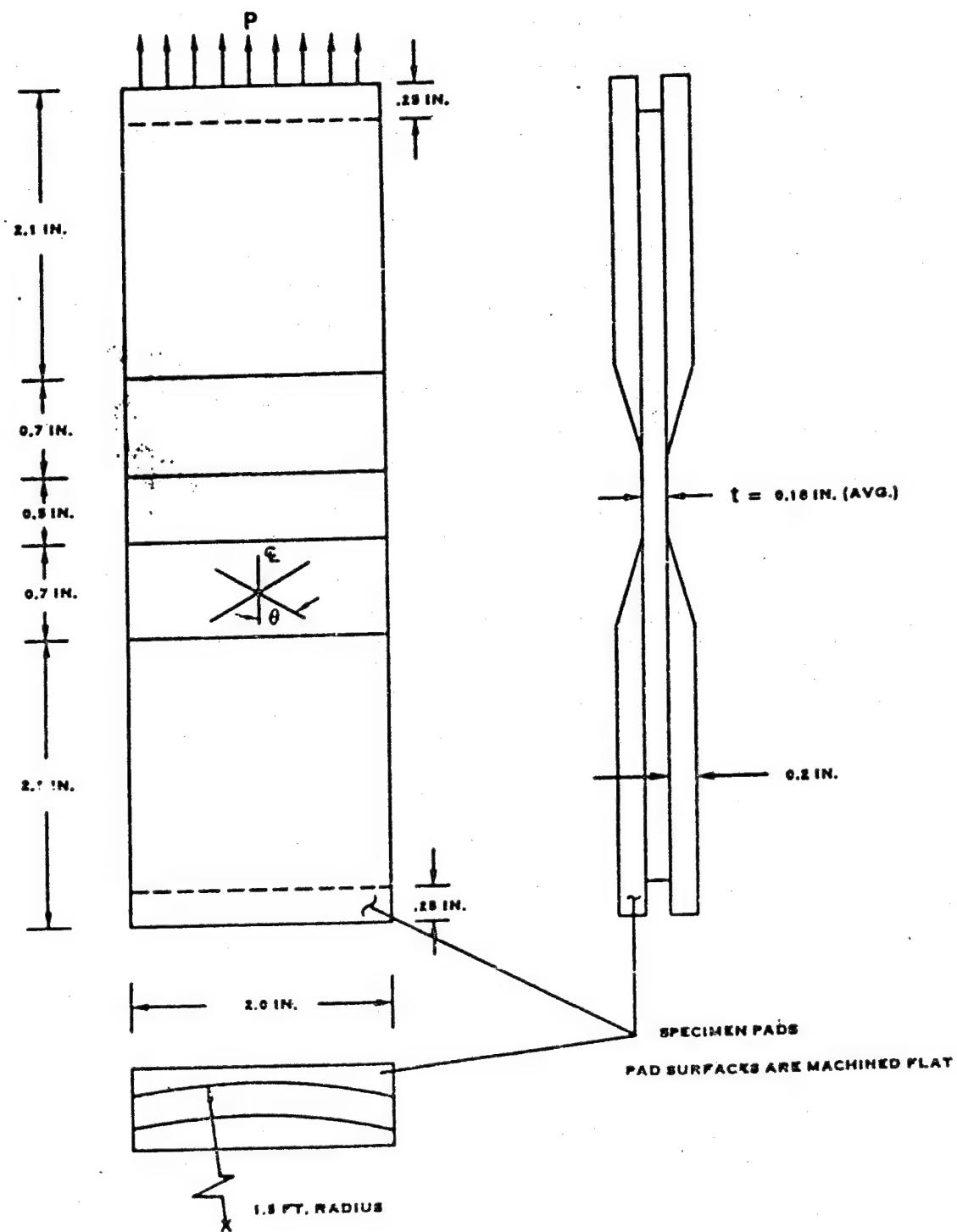
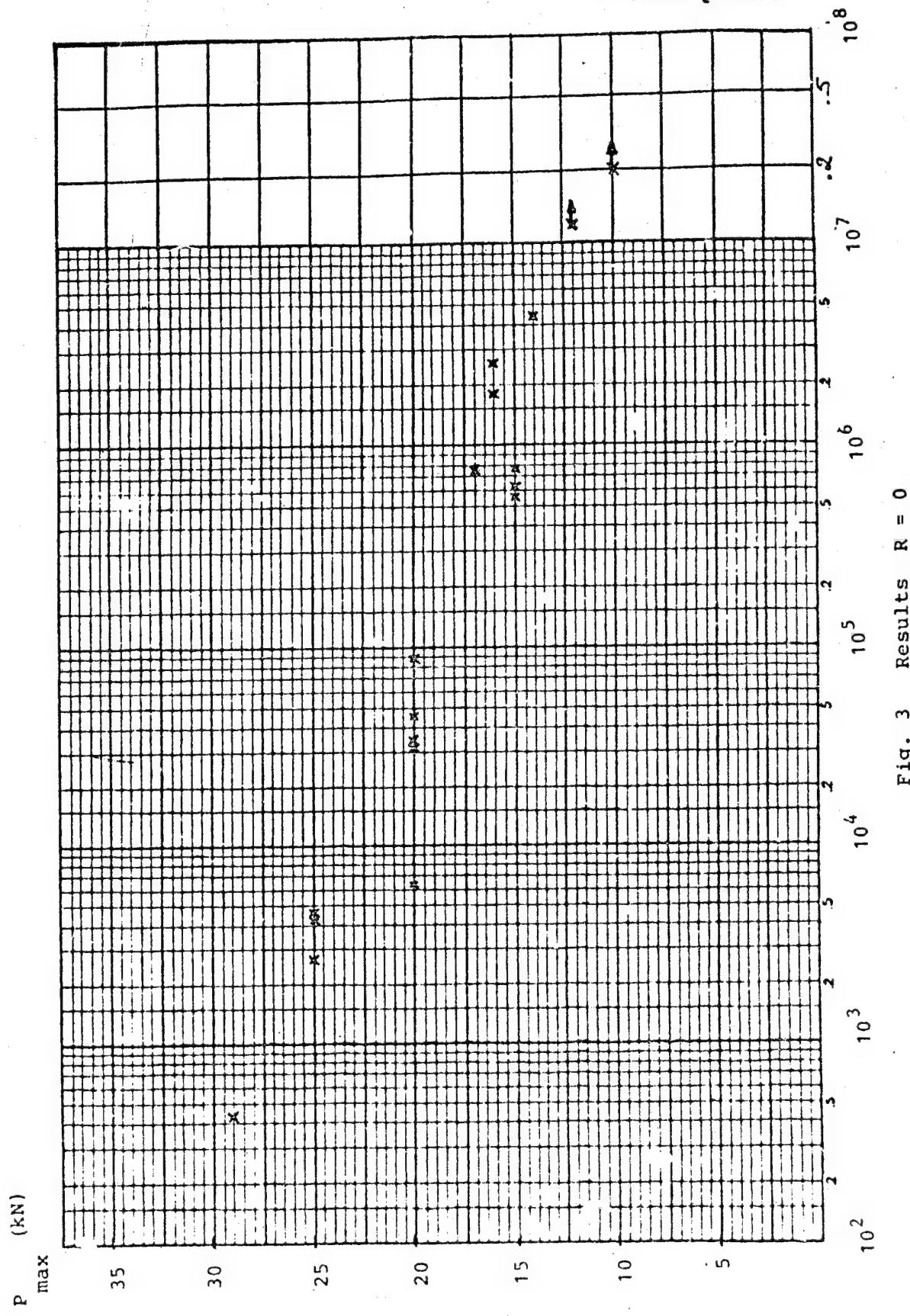
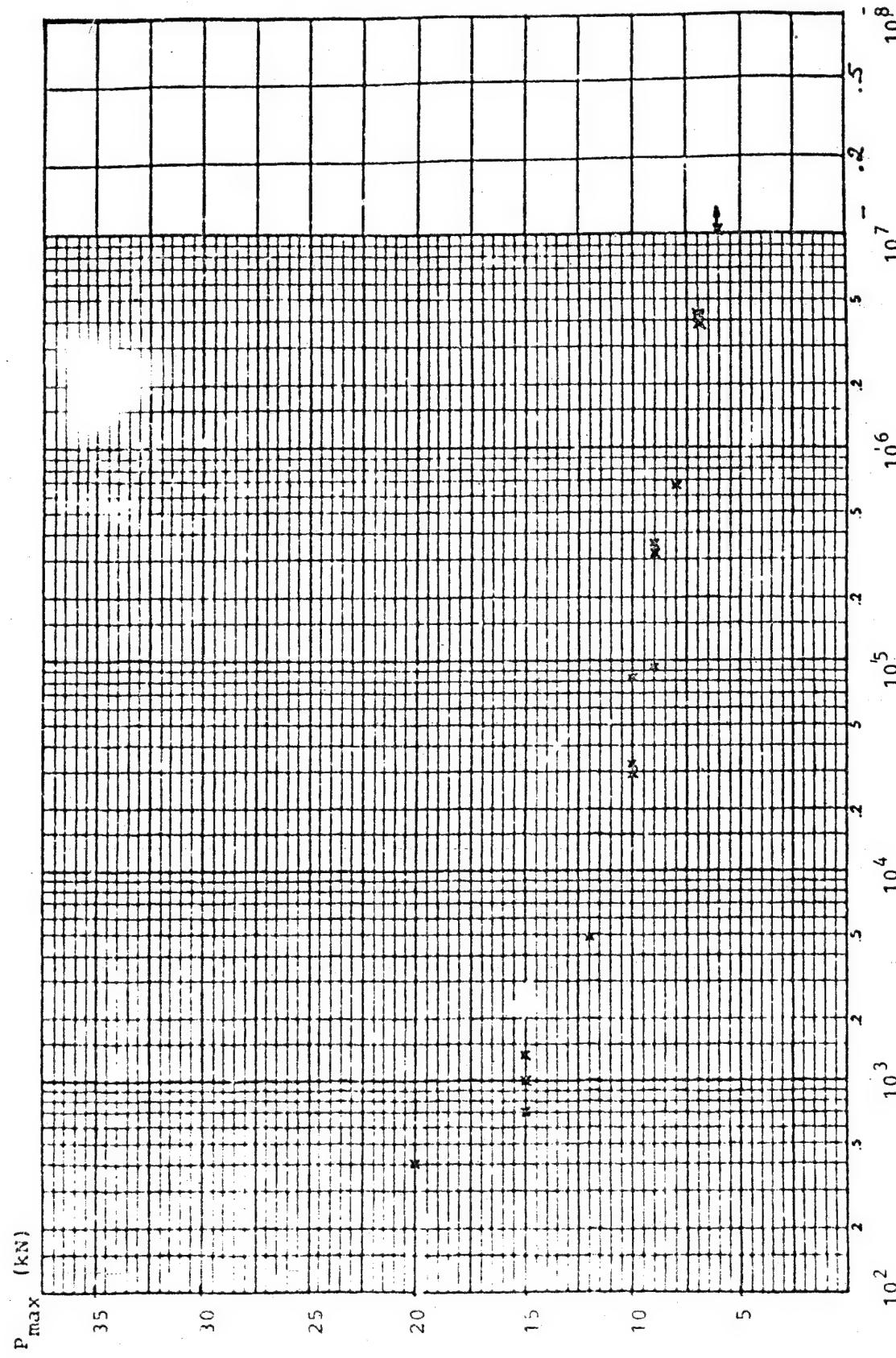
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Fig. 2 Fatigue test specimen

Fig. 3 Results $R = 0$

Fig. 4 Results $R = -1$

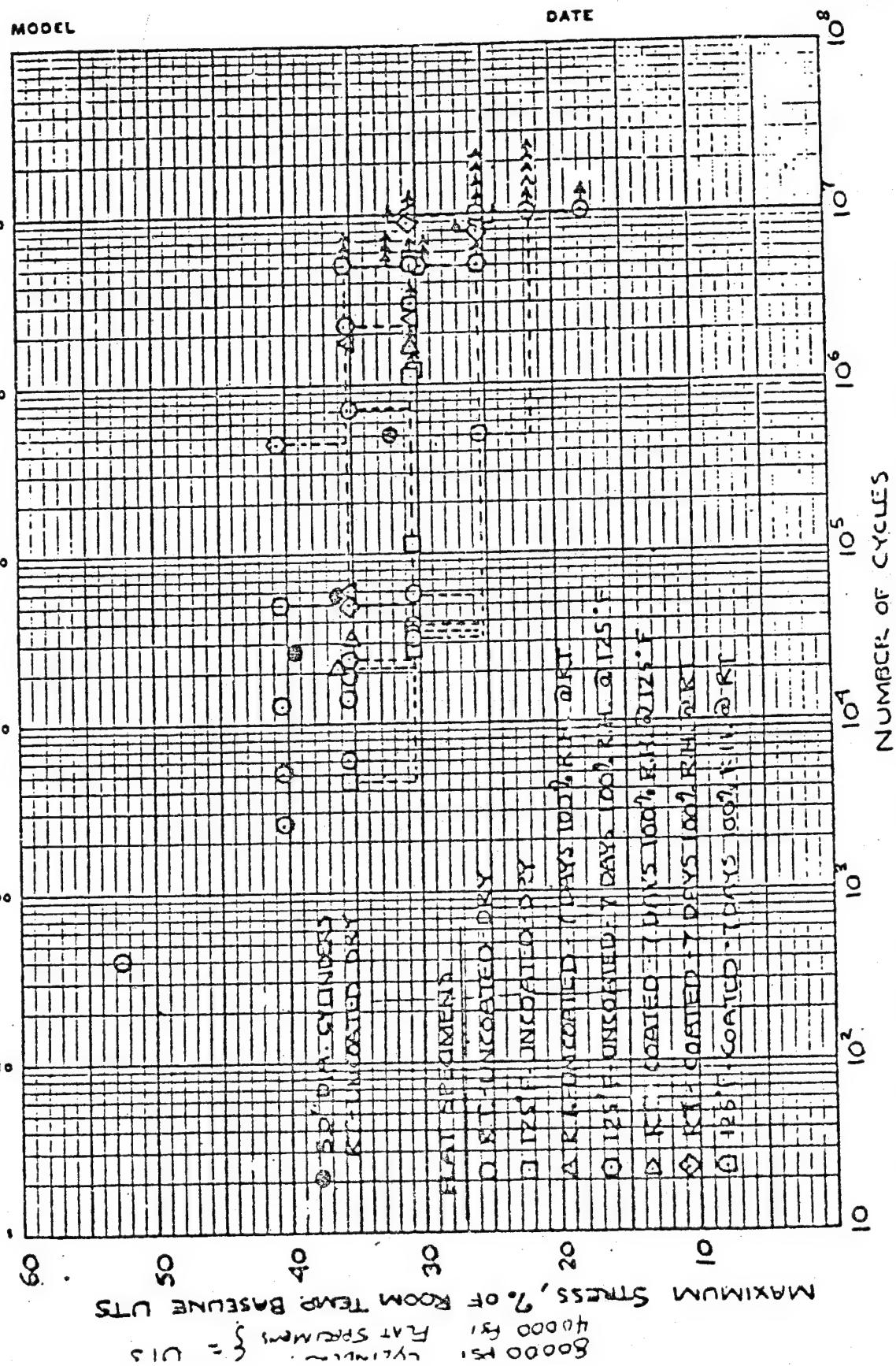


Fig. 5 Fatigue test data from Hamilton Standard. Ref. [5]. $R = 0.1$

8 UTS X = FFA data O = Hamilton Standard data

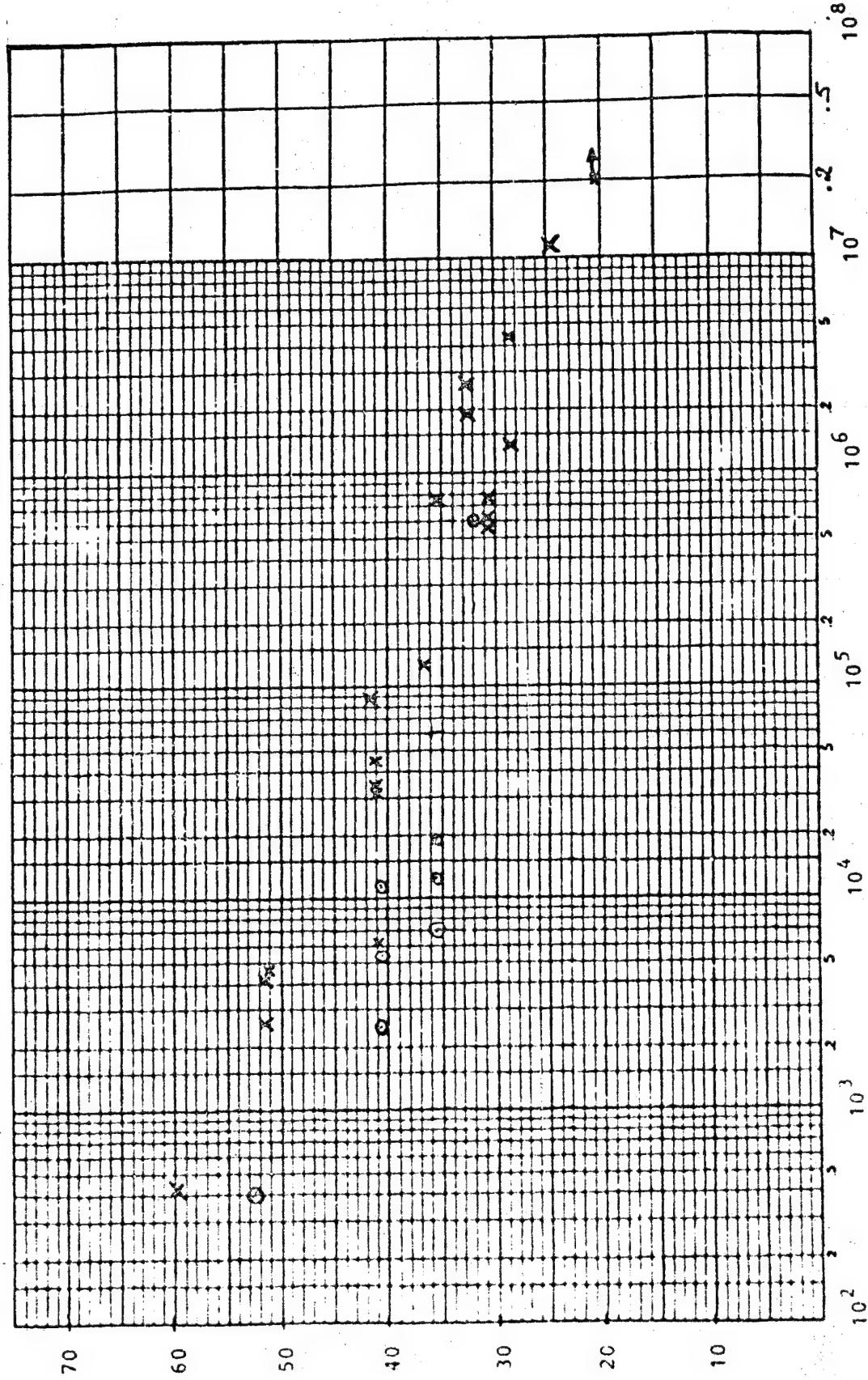


Fig. 6 Comparison of test data

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141-1	5060-141	Nya horisontalaxlade vindturbinaggregat (HA) med integrerade transmissioner. Preliminär granskning av möjliga lösningar	0
151-1	5060-151	Preliminär undersökning av en horisontalaxlad vindturbins prestanda vid snedanblåsning	0
151-2	"	Preliminär konstruktionsgranskning av 4 MW s k HA-Vipparmsaggregat (Storken) med 110 m rotor-diameter	0
151-3	"	Sammanfattande rapport dec 1976 avseende NE-projekten inom vindenergiområdet, nr 5060-141 och 5060-151	0
AU-1447	5060-511	Kravspecifikation	0
DU-1485	5060-511	Funktionsteknisk studie av pilvingerotor	0

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del 2	"	Pilvinkel-Turbin (PVT)-Princip, egenskapsanalys, etapp 1, samt inledande prov 1977		O
del 3	"	Vertikalexslade vindturbinaggregat av Darrieus-typ med fribärande torn, projekt "Poseidon" - Preliminär projektanalys av land- och sjöbaserade versioner		O
del 4	"	Vindturbinaggregat typ "Lill-Poseidon" 200 kW ostagad Darrieus. - Preliminär projektbeskrivning Sjö- och landbaserade varianter		O
del 5	"	Vindturbinaggregat typ "Storken", 4-5 MW. - Preliminära projektutkast, etapp 2		O
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del 8	"	Försök med bandbladsrotor (BB-turbin).		C
del 9	"	Pilvinkelturbin, preliminär undersökning av en PV-modellrotors driftsegenskaper i vindturbinmodellrigg		O
del 10	"	Beskrivning av DUR-nav samt inledande försök med HA- och VA-turbiner i dubbelrotation, november 1977		O
del 11	"	E-DUR-turbinen. Inledande egenskapsprov i FFA vindturbinprovrig, oktober 1977		O
del 12	"	Flerrotors vertikalexslat vindturbinaggregat typ 3-D i 10 MW-klassen, sjöbaserat. - Preliminär projektanalys, etapp 1		O
del 13	"	Preliminära funktionsprov med modell av 3-D vindturbinaggregat, oktober 1977		O
del 14	"	Visualisering i modellskala i två och tre dimensioner (2-D, 3-D) som hjälpmidel vid teknikvärdering avseende miljöestetik för vindturbiner i MW-storlek		O
del 15	"	Sammanfattande överblick av delrapporter inom projekt AU-1416, 1977		

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del 2	"	Inledande försök med Dubbelbladssystem (MPB-variant 1) vid VA/TS-turbiner (Vertikalexlade/Tvärströms-). Oktober 1978	0
del 3	"	Inledande försök med L-bladsarrangemang vid VA/TS-turbiner, bladlastpulsation och turbinprestanda. Oktober 1978	0
del 4	"	Framtagning av en 2x3 m vindtunnelmodell av VA-turbin med tillämpning av dubbelblads- och L-bladssystem, samt med fribärande mast. November 1978	0
del 5	"	Sjöbaseade vindenergisystem i Sverige. - Lokaliseringsmöjligheter, systemutformning, teknikvärdering. November 1978	0
del 6	"	Dynamiska studier av pilvinkel (HA-PV-) turbin, vindbyrespons vid MW-storlekar, jämte inledande experiment med enbladig PV-variant. Januari 1979	0
del 7	"	Vindenergi -Teknisk utlandsuppföljning inom delprogramområdena vertikalexelturbiner (VA-) jämte sjöbasering. Första halvåret 1978. Januari 1979	0
del 8	"	Kompletterande inledande försök med dubbelbladsystem vid VA-turbiner - gällande orkanparke-ringsbuckling, jämte rökströmningsförsök. December 1978	0

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AU-1504 del 8	5060 313	Alternativa konfigurationer Lägesrapport 1 March 1979		0
AU-1504 del 6	5060 313	Förslag till program för utveckling av prototyp till ett vertikaltaxlat vindturbinaggregat med s k L/DB-turbin, typ L-XX, 1,5 - 3 MW December 1979		0
AU-1504 del 4	5060 313	Vertikalaxlad vindturbin typ L-180, 15-20 MW Projektnedladdning av basprojekt alternativ 1 för sjöbasering. January 1980		0
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HU-2229	5061 102	Safety of Wind Energy Conversion System (WECS) with Horizontal Axis February 1981		0
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